1 ParetoMMC.m

```
% ParetoMMC   Pareto optimization for an MMC.
%   Calculate the Pareto frontier with minimum arm energy ripple and conduction
%   loss of an MMC when the second and fourth harmonic of the circulating
%   current is used as free parameters.
%
%   Run ParetoMMC without arguments, or in the editor, to see a demo.
%
%   ParetoMMC attempts to solve
%
%    min F(X, lambda),
%     X
%
%   where F(X, lambda) = E_ripple(X)*lambda + P_loss*(1 - lambda).
%
%   X denotes the amplitudes and phases of the second and fourth harmonic
%   of the circulating current.
%   lambda is the weighting scalar in the range 0 <= lamda <= 1.
%
%   By default, 20 values of lambda are computed.
%
% The MMC dc side is connected to a dc voltage source, while the ac side is
% a symmetric three phase voltage with isolated star point.
% A third harmonic in the common mode voltage is assumed.
%
% [E_ripple_norm, P_loss_norm, circ_current_norm, lambda, F_norm] = ParetoMMC(Rz_norm, m, phi_rad)
%
% Rz_norm = Rz/R_ref normalized arm resistor, with R_ref = UTz/I and UTz
% is the constant part of the lumped semiconductor voltage drop and I is
% the amplitude of the ac current. The U/I slope of the semiconductor
% forward voltage drop and the equivalent resistance of the arm inductor
% can be represented in Rz.
%
% m modulation index, defined as m = 2*V_pk/VDC with V_pk the amplitude of
% the ac voltage and VDC the dc voltage.
%
% phi_rad phase shift between voltage and current on the ac side in radians.
%
% E_ripple_norm is the normalized energy ripple, multiply by
% E_ref = VDC*I/(4*omega) to get the arm energy ripple in SI units.
% omega is the fundamental frequency on the ac side.
%
% P_loss_norm is the normalized loss, multiply by I*UTz to get the arm
% conduction loss in SI units.
%
% circ_current_norm contains the amplitudes in the first and third column
% and the phases in the second and forth column respectively. Multiply the
% amplitudes by I to get the values in SI units.
%
% F_norm corresponding value of the normlized cost function F_norm(X, lambda) = E_ripple_norm(X)*lambda + P_loss_norm*(1 - lambda).
%
% [E_ripple_norm, P_loss_norm, circ_current_norm, lambda, F_norm] = ParetoMMC(
```

```
    Rz_norm, m, phi_rad, nr_points)
%
% nr_points number of points for lambda, defaults to 20 when not given.
%
%
% ParetoMMC.m is part of the MMC Pareto optimization by Mario Lopez and Hendrik Fehr
% This work has been supported by Deutsche Forschungsgemeinschaft
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%
function [E_ripple_norm, P_loss_norm, circ_current_norm, lambda, F_norm] = ParetoMMC(Rz_norm, m, phi_rad, nr_points)

DEMO_RUN = false;

narginchk(0, 4);
if(nargin == 0)
    % Example values for the demo:
    % Loss model parameters for a medium voltage MMC with FZ600R17KE3
    % and twelve cells per arm.
    UTz = 12*0.8414; % 12 times forward voltage drop in Volt
    Rz = 12*2.5e-3 + 6e-3; % 12 times IGBT U/I slope + arm inductor resistance in Ohm
    I = 600*sqrt(2); % amplitude of the ac current
    Rz_norm = Rz/(UTz/I); % caluclate normalized arm resistor

    phi_rad = 0.3491; % load angle on the mmc ac side in rad

    m = 1.05; % modulation index

    nr_points = 20; % number of points to calculate
    DEMO_RUN = true;
elseif(nargin < 4)
    narginchk(3, 3);
    nr_points = 20; % number of points to calculate
end

% TODO add sizes and nan checks
assert(Rz_norm > 0, 'Rz_norm must be positive.');
assert(m >= 0 && m <= 2/sqrt(3), 'm must be non negative and lower than 1.15.');
assert(nr_points > 0, 'nr_points must be positive.');
```

```matlab
assert(phi_rad <= pi && phi_rad >= -pi, 'phi_rad must be in the range of [-pi, pi]');


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% prepare fmincon runs
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Number of points for lambda
lambda_n = nr_points;
starts_n = 8;
Pareto_Ploss = nan*ones(1, lambda_n);
Pareto_Ezrip = nan*ones(1, lambda_n);
Pareto_F = nan*ones(1, lambda_n);
Pareto_x = nan*ones(lambda_n, 4);
Pareto_exitflag = nan*ones(1, lambda_n);
Pareto_lambda = sind(90*linspace(0, 1, lambda_n));

options = optimoptions('fmincon', ...
    'SpecifyObjectiveGradient', true, ...
    'FiniteDifferenceStepSize', [3 0.1 3 0.1]*sqrt(eps), ...
    'CheckGradients', false, ...
    'HonorBounds', false, ...
    'Display', 'off');
A = [];
b = [];
Aeq = [];
beq = [];
nonlcon = [];

lb_ip = [0 -pi 0 -pi];
ub_ip = [1 pi 1 pi];
lb_fc = [-inf -2*pi -inf -2*pi];
ub_fc = [inf 2*pi inf 2*pi];

% prepare the model based circulating current as initial point
Is2_amp_init = m*sqrt(37-12*cos(2*phi_rad)) / 12;
Is4_amp_init = m / 12;
phi_2_init = atan2(-7*sin(phi_rad), 5*cos(phi_rad));
phi_4_init = phi_rad + pi;
x0_mdl = [Is2_amp_init, phi_2_init, Is4_amp_init, phi_4_init];

for i = 1:lambda_n
    the_lambda = Pareto_lambda(i);
    rand_starts = rand(starts_n - 1, 4);
    tmp_F = zeros(1, starts_n);
    tmp_exitflag = zeros(1, starts_n);
    tmp_x = zeros(starts_n, 4);
    x0_v = [lb_ip + rand_starts.*(ub_ip - lb_ip); x0_mdl];
    for k = 1:size(x0_v, 1)
        [tmp_x(k, :), tmp_F(k), tmp_exitflag(k)] = fmincon(@(x) F_eval(x, m, phi_rad, the_lambda, Rz_norm), ...
            x0_v(k, :), A, b, Aeq, beq, lb_fc, ub_fc, nonlcon, options);
    end
    successful_runs = find(tmp_exitflag > 0);
    assert(~isempty(successful_runs), 'no success for %d optimization attempts, cannot continue', starts_n);
    [~, ix] = min(tmp_F(successful_runs));
```

```matlab
    Pareto_exitflag(i) = tmp_exitflag(successful_runs(ix));
    x = tmp_x(successful_runs(ix), :);
    Pareto_x(i, :) = x;
    [~, ~, Pareto_Ezrip(i), Pareto_Ploss(i)] = F_eval(x, m, phi_rad, the_lambda, Rz_norm);
    Pareto_F(i) = Pareto_Ezrip(i)*the_lambda + Pareto_Ploss(i)*(1 - the_lambda);
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% post processing
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% avoid negative arm current amplitudes
for k = [1 3]
    ix_neg_amp = find(Pareto_x(:, k) < 0);
    Pareto_x(ix_neg_amp, k) = -Pareto_x(ix_neg_amp, k);
    Pareto_x(ix_neg_amp, k+1) = wrapToPi(Pareto_x(ix_neg_amp, k+1) + pi);
end

if(lambda_n > 2)
    try
        [ix_hull] = convhull(Pareto_Ezrip, Pareto_Ploss, 'Simplify', true);
        ix_hull = ix_hull(1:end-1);
    catch ME
        if (strcmp(ME.identifier,'MATLAB:convhull:EmptyConvhull2DErrId'))
            % In some cases, convexhull cannot simplify, because the convex
            % hull is empty
            [~, ix_hull] = min(Pareto_Ploss);
            fprintf('Pareto frontier reduces to a single point, continue with caution.\n');
        else
            rethrow(ME)
        end
    end
    discarded = lambda_n - numel(ix_hull);
    if(discarded > 0)
        fprintf('Discarded %d results, which is %1.1f%% of all %d results.\n', discarded, 100*discarded/lambda_n, lambda_n);
    end
    [~, ix_order] = sort(Pareto_lambda(ix_hull));
    ix_plot = ix_hull(ix_order);
else
    ix_plot = 1:lambda_n;
end

% output assignment
E_ripple_norm = Pareto_Ezrip(ix_plot);
P_loss_norm = Pareto_Ploss(ix_plot);
circ_current_norm = Pareto_x(ix_plot, :);
lambda = Pareto_lambda(ix_plot);
F_norm = Pareto_F(ix_plot);

if(~DEMO_RUN)
    % return early when not in demo mode
    return;
end

```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% demo plots
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
figure;
h = plot(Pareto_Ezrip(ix_plot), Pareto_Ploss(ix_plot));
xlabel('normalized energy ripple')
ylabel('normalized arm coduction loss')
title(sprintf('\\phi_o = %.0f [deg], m = %f',phi_rad*180/pi, m));

figure;
subplot(2, 1, 1)
h = plot(Pareto_lambda(ix_plot), Pareto_x(ix_plot, [1 3]));
ylabel('normalized aplitudes')
subplot(2, 1, 2)
h = plot(Pareto_lambda(ix_plot), unwrap(Pareto_x(ix_plot, [2 4]))*180/pi);
ylabel('angle in degree')
xlabel('\lambda')
title(sprintf('\\phi_o = %.0f [deg], m = %f',phi_rad*180/pi, m));
end
```

2 F_eval.m

```
% F_eval  Objective function F evaluation.
%   Evaluate The (scaled and normalized) objective function
%   F(x, lambda) = lambda * E_ripple_norm(x)/E0 + (1 - lambda) * P_loss_norm(x)/P0
%   at the circulating currents given in x and the weighting lambda.
%
%   E_ripple_norm is the normalized energy ripple, multiply by
%   E_ref = VDC*I/(4*omega) to get the arm energy ripple in SI units.
%   I is the output current amplitude, VDC the dc voltage, and
%   omega is the fundamental frequency on the ac side.
%
%   P_loss_norm is the normalized loss, multiply by I*UTz to get the arm
%   conduction loss in SI units. UTz is the constant part of the lumped
%   semiconductor voltage drop.
%
%   The energy ripple is scaled by E0 = 2 and the loss is scalend by
%   P0 = Rz_norm/4 + 1/pi. Rz_norm is explaind below.
%
%   [F, grad_F, Ez_ripp, P_loss, z_sol_all] = F_eval(x, m, phi_o, lambda, Rz_norm)
%
%    x(1) Normalized amplitude of the second current harmonic, Is2, by the output
%          current amplitude.
%    x(2) Phase shift of Is2 in rad.
%    x(3) Normalized amplitude of the fourth current harmonic, Is4, by the output
%          current amplitude.
%    x(4) Phase shift of Is4 in rad.
%
%    m Modulation index defined as m = 2*V_pk/VDC with V_pk the amplitude of
%      the ac voltage and VDC the dc voltage.
%
%    phi_o Displacement angle of the output current I in rad.
```

```
%
%    lambda Weighting scalar in the range 0 <= lamda <= 1.
%
%    Rz_norm = Rz/R_ref normalized arm resistor, with R_ref = UTz/I and UTz
%    is the constant part of the lumped semiconductor voltage drop and I is
%    the amplitude of the ac current. The U/I slope of the semiconductor
%    forward voltage drop and the equivalent resistance of the arm inductor
%    can be represented in Rz.
%
%    F Value of the objective function.
%
%    grad_F(1): gradient of F with respect to the amplitude of Is2.
%    grad_F(2): gradient of F with respect to the phase shift of Is2.
%    grad_F(3): gradient of F with respect to the amplitude of Is4.
%    grad_F(4): gradient of F with respect to the phase shift of Is4.
%
%    E_ripple_norm Normalized energy ripple.
%
%    P_loss_norm Losses.
%
%    z_sol_all: Zero crossing angles of the arm current.
%
%
% F_eval.m is part of the MMC Pareto optimization by Mario Lopez and Hendrik Fehr
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%
function [F, grad_F, E_ripple_norm, P_loss_norm, z_sol_all] = F_eval(x, m, phi_o, lambda, Rz_norm)
    Is2_amp = x(1); % normalized to Io_amp
    phi_2 = x(2);
    Is4_amp = x(3); % normalized to Io_amp
    phi_4 = x(4);
    %
    % normalized arm current wave form
    % iz/I_pk = a + 0.5*cos(z) + b*cos(2*(z + c)) + d*cos(4*(z + e))
    % z = theta + phi_o
    a = m*cos(phi_o)*0.25;
    b = Is2_amp*0.5;
    c = -0.5*phi_2 - phi_o;
    d = Is4_amp*0.5;
```

```
e = 0.25*phi_4 - phi_o;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Roots calculation
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
a_8 = (d*cos(4*e))*0.5+(b*cos(2*c))*0.5+a*0.5-0.25;
a_7 = 4*d*sin(4*e)+2*b*sin(2*c);
a_6 = (-14*d*cos(4*e))-2*b*cos(2*c)+2*a-0.5;
a_5 = 2*b*sin(2*c)-28*d*sin(4*e);
a_4 = 35*d*cos(4*e)-5*b*cos(2*c)+3*a;
a_3 = 28*d*sin(4*e)-2*b*sin(2*c);
a_2 = (-14*d*cos(4*e))-2*b*cos(2*c)+2*a+0.5;
a_1 = (-4*d*sin(4*e))-2*b*sin(2*c);
a_0 = (d*cos(4*e))*0.5+(b*cos(2*c))*0.5+a*0.5+0.25;

z_sol = roots([a_8 a_7 a_6 a_5 a_4 a_3 a_2 a_1 a_0]);
z_sol = z_sol(imag(z_sol) == 0);
if(isempty(z_sol))
    error('No zero crossings found in the arm current.')
end
z_sol = atan(z_sol);

z_sol_all_n = 2*z_sol;
z_sol_all = 2*z_sol - phi_o;
z_sol_all(z_sol_all < 0) = z_sol_all(z_sol_all < 0) + 2*pi;
z_sol_all(z_sol_all >= 2*pi) = z_sol_all(z_sol_all >= 2*pi) - 2*pi;

assert(all(z_sol_all >= 0 & z_sol_all < 2*pi));
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Ez-ripple calculation
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Harm_Is2 = @(t) b*(sin(2*t-phi_2) + m*(-sin(t-phi_2)  ...
    - (1/3)*sin(3*t-phi_2) + (1/30)*sin(5*t-phi_2) + (1/6)*sin(t+phi_2)));
Harm_Is4 = @(t) d*((1/2)*sin(4*t+phi_4) + m*((1/6)*sin(t+phi_4) ...
    - (1/3)*sin(3*t+phi_4) - (1/5)*sin(5*t + phi_4) + (1/42)*sin(7*t+phi_4
        )));

Harm1_Io = @(t) (1 - m^2*0.25)*sin(t+phi_o) - m^2*0.25*sin(t-phi_o);
Harm2_Io = @(t) -m*0.25*sin(2*t+phi_o) + m*1/24*sin(2*t - phi_o);
Harm3_Io = @(t) m^2/72*sin(3*t+phi_o) + m^2/72*sin(3*t-phi_o);
Harm4_Io = @(t) m*1/48 * sin(4*t+phi_o);

Ez1 = @(t) (Harm_Is2(t) + Harm_Is4(t) + Harm1_Io(t) + Harm2_Io(t) +
    Harm3_Io(t) + Harm4_Io(t));

Ez_max = max(Ez1(z_sol_all));
Ez_min = min(Ez1(z_sol_all));
E_ripple_norm = Ez_max - Ez_min;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Ez-ripple gradient calculation
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
[~, z_sol_max] = max(Ez1(z_sol_all));
z_sol_max = z_sol_all(z_sol_max);
```

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    [~, z_sol_min] = min(Ez1(z_sol_all));
    z_sol_min = z_sol_all(z_sol_min);

    dEz_b = @(t) (sin(2*t - phi_2) + m*(7*sin(phi_2)*cos(t) / (6) ...
        - 5*cos(phi_2)*sin(t) / (6) - sin(3*t - phi_2) / (3) + sin(5*t - phi_2) / (30)));
    dEz_d = @(t) (sin(4*t + phi_4) / (2) + m*(sin(t + phi_4) / (6) ...
        - sin(3*t + phi_4) / (3)  - sin(5*t + phi_4) / (5) + sin(7*t + phi_4) / (42)));

    dEz_phi2 = @(t) b*(-cos(2*t - phi_2) + m*(5*sin(phi_2)*sin(t) / (6) ...
        + 7*cos(phi_2)*cos(t) / (6) + cos(3*t - phi_2) / (3) - cos(5*t - phi_2) / (30)));
    dEz_phi4 = @(t) d*(cos(4*t + phi_4) / (2) + m*(cos(t + phi_4) / (6) ...
        - cos(3*t + phi_4) / (3)  - cos(5*t + phi_4) / (5) + cos(7*t + phi_4) / (42)));

    grad_Ez_ripp(1) = (dEz_b(z_sol_max) - dEz_b(z_sol_min))*0.5;
    grad_Ez_ripp(2) = (dEz_phi2(z_sol_max) - dEz_phi2(z_sol_min));
    grad_Ez_ripp(3) = (dEz_d(z_sol_max)- dEz_d(z_sol_min))*0.5;
    grad_Ez_ripp(4) = (dEz_phi4(z_sol_max)- dEz_phi4(z_sol_min));
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    % Ploss
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    z_sol_all_n = sort(z_sol_all_n);
    z = [-pi z_sol_all_n' pi];

    Iz = @(t) a + 0.5*cos(t) + b*cos(2*t + 2*c) + d*cos(4*t + 4*e);
    Iz_avg_1 = @(t) a*t + 0.5*sin(t) + 0.5*b*sin(2*t + 2*c) + 0.25*d*sin(4*t + 4*e);
    P_loss_norm = Rz_norm*(a.^2 + (0.25 + b.^2 + d.^2)*0.5);
    for i = 1:(numel(z)-1)
        P_loss_norm = P_loss_norm + 0.5/pi*sign(Iz((z(i)+z(i+1))/2))*(Iz_avg_1(z(i+1)) - Iz_avg_1(z(i)));
    end

    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    % Iavg losses gradient calculation
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    grad_P_loss(1) = 0;
    grad_P_loss(2) = 0;
    grad_P_loss(3) = 0;
    grad_P_loss(4) = 0;
    for i = 1:(numel(z)-1)
        grad_P_loss(1) = grad_P_loss(1) + sign(Iz((z(i)+z(i+1))/2))*(sin(2*z(i+1) + 2*c) - sin(2*z(i) + 2*c));
        grad_P_loss(2) = grad_P_loss(2) - 2*b*sign(Iz((z(i)+z(i+1))/2))*(cos(2*z(i+1) + 2*c) - cos(2*z(i) + 2*c));
        grad_P_loss(3) = grad_P_loss(3) + sign(Iz((z(i)+z(i+1))/2))*(sin(4*z(i+1) + 4*e) - sin(4*z(i) + 4*e));
        grad_P_loss(4) = grad_P_loss(4) + 2*d*sign(Iz((z(i)+z(i+1))/2))*(cos(4*z(i+1) + 4*e) - cos(4*z(i) + 4*e));
    end
    grad_P_loss(1) = (1/(8*pi))*grad_P_loss(1);
```

```
    grad_P_loss(2) = (1/(8*pi))*grad_P_loss(2);
    grad_P_loss(3) = (1/(16*pi))*grad_P_loss(3);
    grad_P_loss(4) = (1/(16*pi))*grad_P_loss(4);
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    % Irms gradient calculation
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    grad_P_loss(1) = Rz_norm*2*b/4 + grad_P_loss(1);
    grad_P_loss(3) = Rz_norm*2*d/4 + grad_P_loss(3);
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    % F calculation
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    q1 = 0.5;
    q2 = 1/(Rz_norm*.125 + 1/pi);

    F = q1*lambda*E_ripple_norm + q2*(1-lambda)*P_loss_norm;
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    % F gradient calculation
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    grad_F = q1*lambda*grad_Ez_ripp + q2*(1-lambda)*grad_P_loss;
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
end
```

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in a fashion requiring copyright permission, other than the making of an
exact copy.  The resulting work is called a "modified version" of the
earlier work or a work "based on" the earlier work.

  A "covered work" means either the unmodified Program or a work based
on the Program.

  To "propagate" a work means to do anything with it that, without
permission, would make you directly or secondarily liable for
infringement under applicable copyright law, except executing it on a
computer or modifying a private copy.  Propagation includes copying,
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distribution (with or without modification), making available to the
public, and in some countries other activities as well.

  To "convey" a work means any kind of propagation that enables other
parties to make or receive copies.  Mere interaction with a user through
a computer network, with no transfer of a copy, is not conveying.

  An interactive user interface displays "Appropriate Legal Notices"
to the extent that it includes a convenient and prominently visible
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extent that warranties are provided), that licensees may convey the
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the interface presents a list of user commands or options, such as a
menu, a prominent item in the list meets this criterion.

  1. Source Code.

  The "source code" for a work means the preferred form of the work
for making modifications to it.  "Object code" means any non-source
form of a work.

  A "Standard Interface" means an interface that either is an official
standard defined by a recognized standards body, or, in the case of
interfaces specified for a particular programming language, one that
is widely used among developers working in that language.

  The "System Libraries" of an executable work include anything, other
than the work as a whole, that (a) is included in the normal form of
packaging a Major Component, but which is not part of that Major
Component, and (b) serves only to enable use of the work with that
Major Component, or to implement a Standard Interface for which an
implementation is available to the public in source code form.  A
"Major Component", in this context, means a major essential component
(kernel, window system, and so on) of the specific operating system
(if any) on which the executable work runs, or a compiler used to
produce the work, or an object code interpreter used to run it.

  The "Corresponding Source" for a work in object code form means all
the source code needed to generate, install, and (for an executable
work) run the object code and to modify the work, including scripts to
control those activities.  However, it does not include the work's
System Libraries, or general-purpose tools or generally available free
programs which are used unmodified in performing those activities but
which are not part of the work.  For example, Corresponding Source
includes interface definition files associated with source files for
the work, and the source code for shared libraries and dynamically
linked subprograms that the work is specifically designed to require,
such as by intimate data communication or control flow between those
subprograms and other parts of the work.

  The Corresponding Source need not include anything that users
can regenerate automatically from other parts of the Corresponding
Source.

  The Corresponding Source for a work in source code form is that
same work.
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  You may convey a covered work in object code form under the terms
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in one of these ways:

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    Corresponding Source fixed on a durable physical medium
    customarily used for software interchange.

    b) Convey the object code in, or embodied in, a physical product
    (including a physical distribution medium), accompanied by a
    written offer, valid for at least three years and valid for as
    long as you offer spare parts or customer support for that product
    model, to give anyone who possesses the object code either (1) a
    copy of the Corresponding Source for all the software in the
    product that is covered by this License, on a durable physical
    medium customarily used for software interchange, for a price no
    more than your reasonable cost of physically performing this
    conveying of source, or (2) access to copy the
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    Corresponding Source from a network server at no charge.

    c) Convey individual copies of the object code with a copy of the
    written offer to provide the Corresponding Source.  This
    alternative is allowed only occasionally and noncommercially, and
    only if you received the object code with such an offer, in accord
    with subsection 6b.

    d) Convey the object code by offering access from a designated
    place (gratis or for a charge), and offer equivalent access to the
    Corresponding Source in the same way through the same place at no
    further charge.  You need not require recipients to copy the
    Corresponding Source along with the object code.  If the place to
    copy the object code is a network server, the Corresponding Source
    may be on a different server (operated by you or a third party)
    that supports equivalent copying facilities, provided you maintain
    clear directions next to the object code saying where to find the
    Corresponding Source.  Regardless of what server hosts the
    Corresponding Source, you remain obligated to ensure that it is
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    you inform other peers where the object code and Corresponding
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  A separable portion of the object code, whose source code is excluded
from the Corresponding Source as a System Library, need not be
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and execute modified versions of a covered work in that User Product from
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code is in no case prevented or interfered with solely because
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User Product is transferred to the recipient in perpetuity or for a
fixed term (regardless of how the transaction is characterized), the
Corresponding Source conveyed under this section must be accompanied
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by the Installation Information. But this requirement does not apply if neither you nor any third party retains the ability to install modified object code on the User Product (for example, the work has been installed in ROM).

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